Energy Reports 6 (2020) 1702–1714

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Research paper

Decentralized biomass for biogas production. Evaluation and potential assessment in Punjab (India)

Buta Singh [a,*], Zoltán Szamosi [a], Zoltán Siménfalvi [a], Martí Rosas-Casals [b]

[a] Institute of Energy Engineering and Chemical Machinery, University of Miskolc, Hungary
[b] Sustainability Measurement and Modeling Lab, Universitat Politécnica de Catalunya, BarcelonaTech, Spain

ARTICLE INFO

Article history:
Received 16 October 2019
Received in revised form 18 April 2020
Accepted 15 June 2020
Available online xxxx

Keywords:
Biogas power plants
Power production
Punjab
Renewable energy sources

ABSTRACT

Punjab state has huge potential of conversion of biomass to energy that can produce estimated 3172 MW power which is the highest among all the states in India. All the developing countries are struggling with increasing energy demand and the environmental pollution. The renewable and sustainable energy resources are the best substitute to the conventional fuels and the energy sources. India is the third largest energy consumer and the third largest greenhouse gas emitting country. In the case of the state of Punjab, which is one of the top producers of biomass in the country, the share of renewable energies is still dwarfish in spite of significant opportunities. Conversion of biogas to electricity is the standard technology and power generation is the main purpose of biogas plants in the developed countries but in India it is still used as bio-CNG. Here we aim at analyzing the development and the scope of conversion of biogas to electricity in the state of Punjab in India. Massive amount of decentralized biomass resources is available in the state and there is huge potential to use this technology due to availability of biomass from the animal waste, the agriculture and the households. This study also focuses on the economic evaluation of a large-scale biogas plant in context of Indian government framework for development to the projects along with the current scenario of renewable energy resources and the power production by the large-scale Biogas power plants. Our findings show that the biogas production provides an attractive investment opportunity in the state, especially for the large-scale farms and the decentralized animal waste. Power generation to cope up the needs of Punjab can be more practicable and an environment friendly by biogas power plants as there is abundance of an organic waste material, an appropriate infrastructure and the suitable climate.

1. Introduction

Drastically increasing world population and changing lifestyle of people is resulting in intensification of energy demand around the globe. In the present era, the fossil fuels and the conventional energy resources have major share in power production which is leading to the menacing issue of global warming and climate change. In 2012 the world energy consumption was estimated as 557 EJ/yr with only 10% from the biofuels and waste (Agency IE, 2014). Due to the alarming consequences of use of fossils, mankind is forced to opt renewable energy resources and reduce carbon emissions. India is the third largest energy consuming and the third largest greenhouse gas emitting country in the world (Ksabas, 2018). India is producing 10% of global coal but state-owned coal company, Coal India Ltd (CIL) is facing problems due to the outdated technology and logistics, destabilizing coal supply which is leading to the higher imports (Ksabas, 2018). Meanwhile, the upgradation of energy resources seems to be limited to the developed countries. For an instance, in developing countries like India and China the economies are boosting at high rate, so, it is substantial challenge to maintain the environment and the economic development parallelly (Mittal et al., 2016). The main reason of lagging behind in resource development is lack of infrastructure, management and awareness among the people (Hossain, 2014). According EY 2019 reports India ranks 4th place in RECAI dropping from rank 3nd in 2018 (Young, 2014). Indian government aims to add capacity of 175 GW in renewable power until 2022 which will include 100 GW solar, 60 GW wind, 10 GW biomass and 5 GW small hydro power (kumar, 2017). Biomass/organic matter is a source of greenhouse gases like methane, carbon dioxide, hydrogen sulfide and other gases when undergoes anaerobic digestion (Chen et al., 2008). AD is a microbial process which is carried in absence of oxygen resulting in biogas. A biogas plant can convert animal manure, green plants, waste from Argo industry and slaughterhouses into combustible

* Corresponding author.
E-mail addresses: vegybs@uni-miskolc.hu (B. Singh), vegyszam@uni-miskolc.hu (Z. Szamosi), vegysi@uni-miskolc.hu (Z. Siménfalvi), marti.rosas@upc.edu (M. Rosas-Casals).

https://doi.org/10.1016/j.egyr.2020.06.009

Nomenclature

QAD	Quantity of animal dung
N	Number of animals
D	Amount of dung produced per animal [kg]
Q_{RS}	Quantity of rice straw [kt a^{-1}]
P_{RR}	Rough rice production [kt a^{-1}]
SGR	Straw to grain ratio
T_1	Current temperature of slurry (°C)
r_o	Radius of circular area [km]
q_c	Local capacity of transport unit [ton]
C_t	Unit cost of biomass transport [Rs]
Z	Unit cost of power production [Rs/kWh]
M_o	Capacity of plant (kW) with known capital C_o [Rs]
K_o	Capital cost of plant [Rs]
f	Capital recovery cost [Rs]
n	Number of years of life
h	Plant operating hours per year
R_o	Non-fuel, operating cost [Rs/kWh]
Q_i	Energy potential in GJ/year
η_c	Conversion efficiency
Q_T	The total heat (energy required for heating the slurry) kJ
m	Mass of slurry (kg)
c	Specific heat of slurry (kJ/(kg °C))
T_2	Desired temperature of slurry (°C)
ρ	Spatial density of biomass [t/km^2]
C_r	Biomass recovery cost [Rs]
C_c	Unit collection cost [Rs]
M	Capacity of plant [kWh]
s	Scale factor representing the economy of scale of plant
M_{opt}	Optimal capacity of plant [kW]
i	Annual interest rate on capital
E	Technological conversion coefficient [kWh/t]
H	Fuel heating value [MJ/t]
η	Plant thermal efficiency

Acronyms

AD	Anaerobic digestion
MW	Megawatt
RECAI	Renewable energy country attractiveness index
kWh	Kilowatt hour
SHP	Small Hydro Plant
RE	Renewable Energy
MNRE	Ministry of New & Renewable Energy
CPCB	Central Pollution Control Board
MSW	Municipal Solid Waste
MNES	Ministry of Non-conventional Energy Sources
DRES	Decentralized renewable energy resources
FDI	Foreign Direct Investment
MSW	Municipal solid waste
CHP	Combined heat and power
MCM	Million cubic meters
GEF	Global Environment Facility
VS	Volatile solids
PEDA	Punjab Energy Development Agency
NABARD	National Bank of Agriculture and Rural Development
IREAD	Indian Renewable Energy Development Agency
SIDBI	Small Industries Development Bank of India
MMT	Million metric ton
QAD	Quantity of animal dung
HRT	Hydraulic retention time
BDTC	Biogas development and training centers
MSWM	Municipal solid waste management
HHV	Higher heating value

gas. Biogas produced through an anaerobic digestion process consist of 50%–70% methane, 25%–40% carbon dioxide and 2%–8% of water vapors and traces of O_2, N_2, NH_3, H_2S. Biogas can be used for various heating and power generation purposes. The digestate is a mixture of solid and liquid which can be directly used as an organic fertilizer in the agricultural land to retain the nutrients and fertility of soil. Sometimes biogas is upgraded to enhance the calorific value of gas. Assuming biogas with 60% methane, the energy content will be 6 kWh per normal cubic meter whereas when it is upgraded to 97% methane energy content will be 9.67 kWh/Nm^3. According to the study by Sefeedpari et al. (2012) on production of one kilowatt-hour of electricity from biogas, there is reduction of 414g of CO_2 emissions.

Renewable energy resources are heavily supported in the country as they are well suited for the resources and the energy needs. In India biogas is primarily used for cooking and heating in the households (Sooch et al., 2013). Since 1994–95 175,000 the domestic biogas plants have been running across the Punjab state. Biogas produced from these small scale plants is used for cooking purposes only which took over 2100 tones of wood, traditionally used as fuel. Despite of tremendous amount of available biomass in form of crop residue and animal waste, Punjab lacks in large scale high rate Bio-methanation power projects. This can be a magnificent alternative in terms of reduction of greenhouse gases and profit. The State has high power consumption per capita as compared to the average national value of India. At present in state of Punjab the majority of power production is from the conventional sources of energy such as coal, gas and diesel. Power production from high rate bio-methanation plants is very opportune source of energy which is appropriate for reduction of greenhouse gases and solid and liquid waste management. From last few decades the quantity of agricultural (Trivedi et al., 2017) as well as municipal waste is increasing with high rates. Moreover, around 12 million tons of rice straw is burned every year in Punjab creating immense environmental issues of both air and soil pollution (Sood, 2015). Government of India aims to achieve 244 MW of biomass power generation by 2022 in state of Punjab.

An adequate and reliable availability of power is an indispensable for sustainable growth of the economy. Power generation to cope up the needs of Punjab can be more practicable and environment friendly by biogas power plants as there is an abundance of organic raw material, an appropriate infrastructure and a suitable climate. Renewable energy sector can play a vital role in establishing new industry by developing the routines in a path-dependent and idiosyncratic manner (Ksabas, 2018).

The present work focuses on the assessment of availability of biomass and its scope for biogas production on a large scale in Punjab state. It also focuses on the role of authority, policies, division of labor and infrastructure in the location. The outline of this work is to evaluate the opportunity of production of electricity from the available biomass through high rate bio methanation biogas plants in the state by including the type of substrates, quality and quantity of biomass, desirable economic and environmental conditions, problems associated with the collection, management and distribution of decentralized biomass and market. The present study has been undertaken with the following objectives:

- Evaluate recent developments, future scope and prospective of biogas power generation in Punjab.
- Assessment of available biomass for large scale biogas plants.
- To discover investment opportunity in the state especially for large scale farms and decentralized animal waste.
- To discuss the potentials, obstacles and necessary framework conditions for the utilization of biogas.

2. Anaerobic digestion process

Anaerobic digestion is a complex process which include series of steps such as hydrolysis, acidogenesis, acetogenesis/ dehydrogenation, and methanation (Fig. 2) (Appels et al., 2008). The substrate can be any organic matter such as agricultural waste, kitchen waste, municipal solid waste and slaughterhouse waste. Anaerobic digestion of an organic matter results in formation of biogas which is composition of methane (60%–70%), carbon dioxide (25%–30%) and various other impurities such as hydrogen sulfide, ammonia etc. The byproducts of biogas plant are biofertilizer, compost and reusable water. The biofertilizer can be used directly in the fields as an organic manure and the liquid material can be reused in the anaerobic digester to enhance biogas production (Anjum et al., 2011). Fig. 1 represents the detailed flow process including the various types of possible substrates as input in an anaerobic digester along with the primary products produced through anaerobic digestion process. Fig. 2 demonstrates step by step sequence of the biochemical reactions and microbes involved in the overall digestions process.

2.1. Biogas to power technology

One of the main challenges for the developing countries is how to produce the secure and cheap electricity in order to fulfill the increasing demand and at the same time reduce the carbon emissions. Biogas to electricity conversion is most trending and commonly used technology in developed countries. Moreover, the cost of electricity production from biogas can be lower than other renewable energies and fossil fuels (Budzianowski, 2011). This technology can be encouraged in Punjab due to several economic and environment reasons. There are different technologies to convert chemical energy of biogas to thermal and mechanical energy and finally to the electrical energy listed below (Wang et al., 2014).

- Pressurized steam produced by combustion of biogas can be used to drive steam turbines which can drive the generators to produce electricity.
- Biogas can be used to power Stirling engine that uses external combustion system (combustion takes place outside the engine)
- Internal combustion engines can also use biogas as a primary fuel to produce mechanical power and finally electrical power.

Basically, the chemical energy of biogas can be converted to mechanical energy by the internal combustion engines. In this system the pressurized biogas can be directly used as a fuel for a gas engine without any upgradation. CHP refers to Combined heat and power operation. CHP technology involves gas engines, micro gas turbines or dual fuel engines. The mechanical energy obtained from the engines derives the generators to produce electrical energy. CHP engines simultaneously produces useful heat which can be used for various other purpose such as heating the slurry in the digester and households (Niels Sacher (Xavier University) , 2019). Fig. 3 represents the Flow chart of technologies for conversion of biogas to electricity.

3. Material and method

This study is based on the primary research such as field survey, direct interaction with farmers from the villages and also the secondary data collection from government resources of state in agriculture sector. The investigation was based on the direct interviews with the households at level zero. The information regarding the collection and storage facilities and the costs was collected from existing power plants that generates power either by burning of paddy straw or ethanol production. Direct interaction was possible with few families from district Mansa and the power plants located in Jaito, Faridkot and Muktsar district in Punjab. This helped us to ensure the exact data related to the biogas production and the related costs from the particular geographical topo geographical area. Besides primary data, the secondary data was also collected from various sources such as government annual reports, newspaper articles and the official government websites.

4. Case study description

4.1. Profile of state of Punjab (India)

Punjab is a state in northern India. The state covers area of 50,362 km^2 and is the 20th largest state in country by area and the 16th largest by population. The soil in Punjab is fertile, alluvial plains with many rivers and extensive canal system which creates a very favorable environment for agriculture in the state. The northeastern end of state extends along foothills of Himalayas. The average elevation is 300 m above sea level, with range from 180 m in southwest to more than 500 ms to northeastern border.

Punjab is predominantly rich in agriculture and contributes the major share to the grain basket of India. It has surplus production of major crops. Punjab produces 55% of country's rice and 22% of wheat having 1.5% of total cultivable area of country. Despite of unnatural habitat of rice in Punjab, it is grown extensively from last few decades. High yielding varieties of the seeds and use of chemical fertilizers has placed a great demand on irrigation facilities (Chaba, 2019). This demand is met by energizing submersible pumps. Despite of numerous natural water resources of its own, agriculture in Punjab mainly depends on ground water due to which the ground water of Punjab is arduously used, and tremendous amount of electric power is consumed every year to draw water from ground by electric submersible pumps. In the peak season of paddy plantation, the power demand in state touches to 12 775 MW per day due to presence of 1.5 million energized pumps to draw ground water. The electric power needed for irrigation is produced mainly by non-conventional energy resources mainly from coal powered thermal power plants. Neither coal mines nor oil wells are found in the state. For this instance, Punjab depends on other states of India for coal which is neither economically nor environmentally feasible.

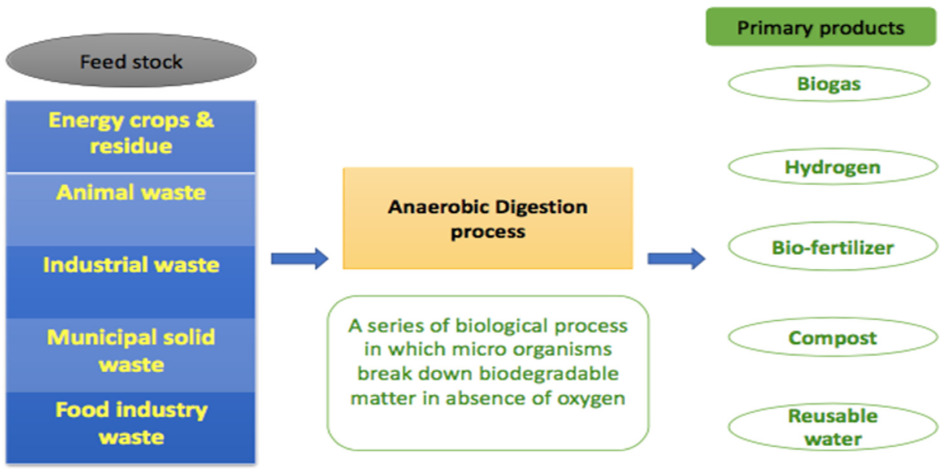

Fig. 1. Schematic representation of basic process of biogas production.

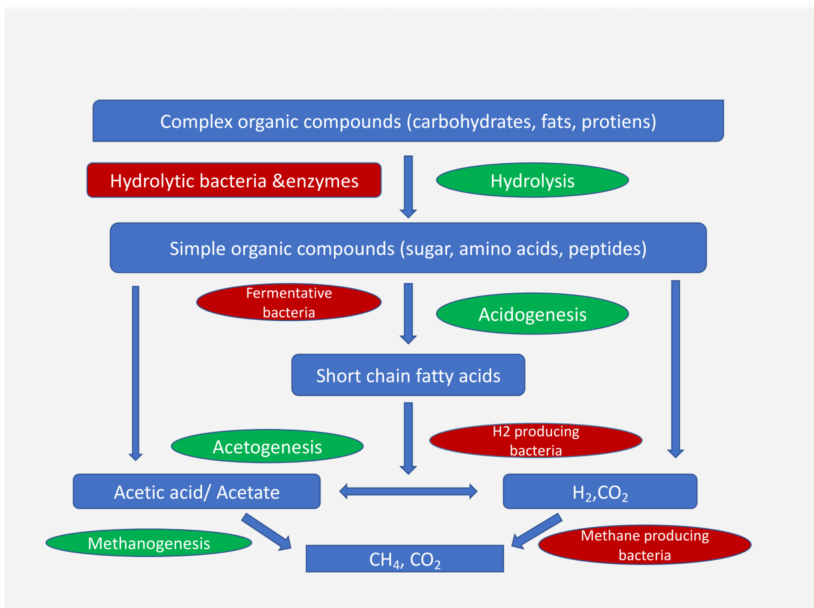

Fig. 2. Various chemical processes involved in the anaerobic digestion process for conversion of organic matter into combustible gas.

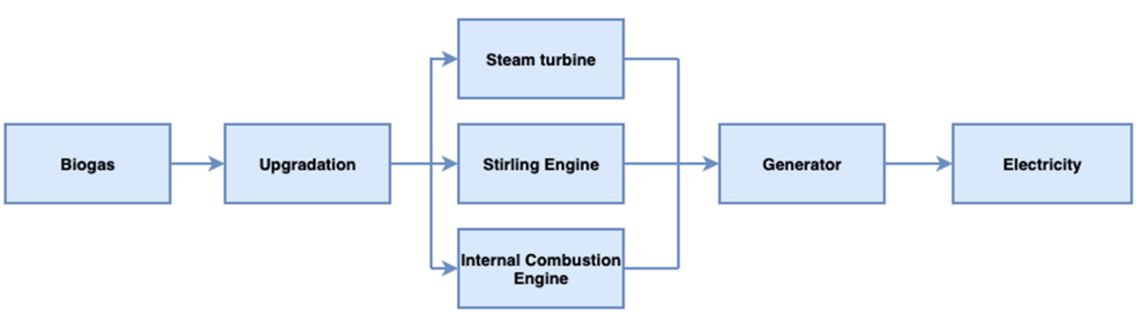

Fig. 3. Flow chart of technologies for conversion of biogas to electricity.

4.2. Power statistics

Energy is the most important factor that plays vital role in development of overall economy of state. Adequate and reliable availability of power is an indispensable for sustainable growth of the economy. Due to the mechanization of agriculture, the rapid growth of industrialization and the transportation, it is quite hard challenge to meet the power needs of state unless new sources of energy are tapped (Luthra, 0000). In the past Punjab was experiencing immense shortage of power despite of huge investment in this sector. In the recent times Punjab has transformed from a power deficit state to power surplus state due to rapidly grown power sector industry but by means of non-conventional energy resources. Majority of the power production

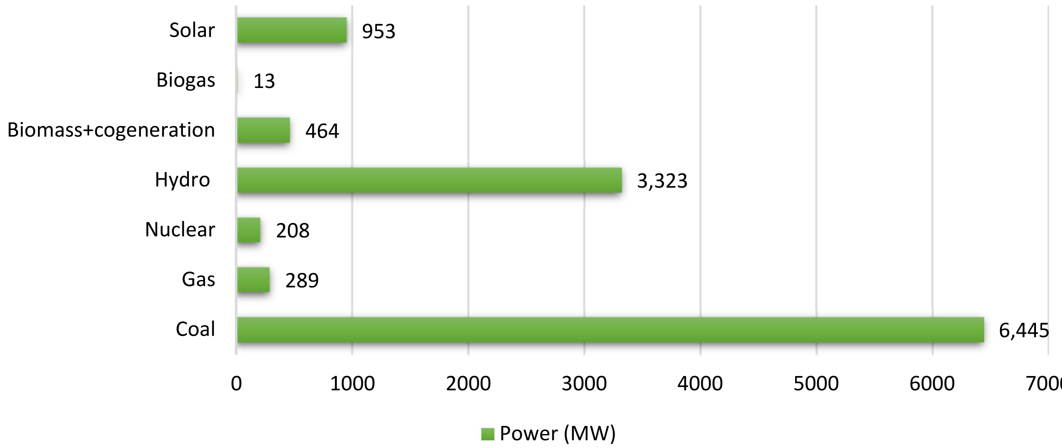

Fig. 4. Sources of power production in Punjab.

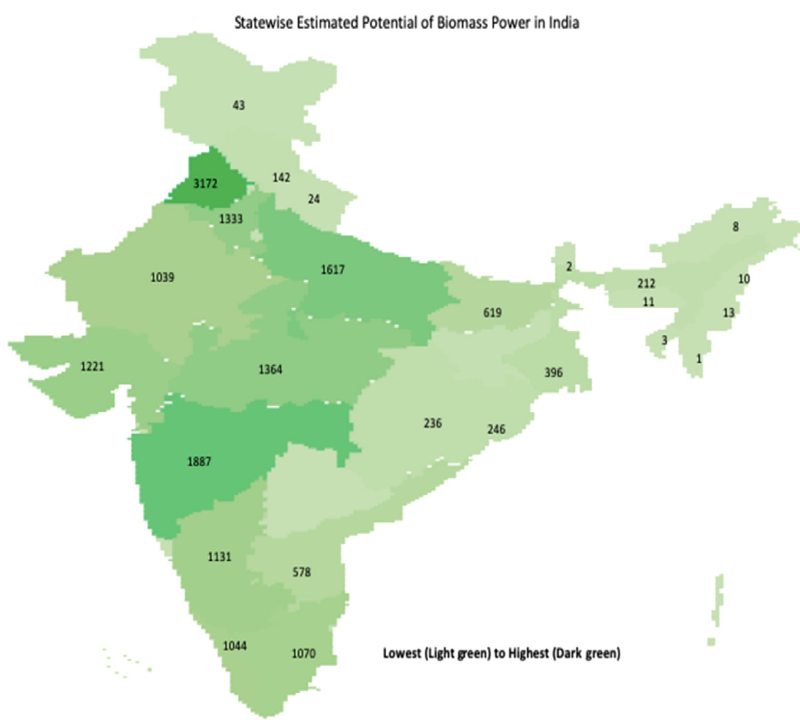

Fig. 5. Distribution of biomass among different states in India.

is from thermal power plants. Fig. 4 demonstrates the distribution of power production by the various energy resources. It can be clearly stated that the major portion of power in the state is contributed by non-renewable energy resources which include coal and gas.

Punjab is among the high power intensive states is India, with per capita power consumption twice that of national average. The total number of units consumed for different purpose was 3,97,554 lakh kWh in 2014–15 which increased to 407 679 lakh kWh in 2015–16 reflecting an increase of 2.55 percent over the previous year. Regarding per capita consumption of electricity, Punjab has 1377 kWh during 2015–16 against 1360 kWh during 2014–15 (Adviser, 2015).

4.3. Present scenario of biogas in Punjab

India has huge potential of renewable energy production from wind, hydro power, solar and biomass. According to report by Ministry of statistic and programme implementation (Government of India) total estimated potential of renewable energy in India is 1 198 856 MW in year 2016–17 (CSO, 2015). The total biomass reserves contribute to 17 538 MW of total power across the country from which 18% of biomass is available in Punjab only which is highest among all other states. Fig. 5 demonstrates the distribution of power production from biomass in various states in India. It can be clearly stated that Punjab state have potential of producing 3172 MW power from biomass pushing it on the top of the list. Moreover, the interesting fact unfurled is that despite of huge potential of renewable energy production in the state the present utilization of these resources is quite low (Fig. 6).

Domestic biogas plants were hugely encouraged in the last few decades. There are around 4.5 million domestic biogas plants in India. For improving the rural economy and enabling the best use of cattle dung to provide smoke free cooking fuel, the cattle dung is put into a specially designed structure called a “Biogas Plant”, where, after anaerobic digestion of the same, biogas is produced. The remaining material, called slurry, containing about

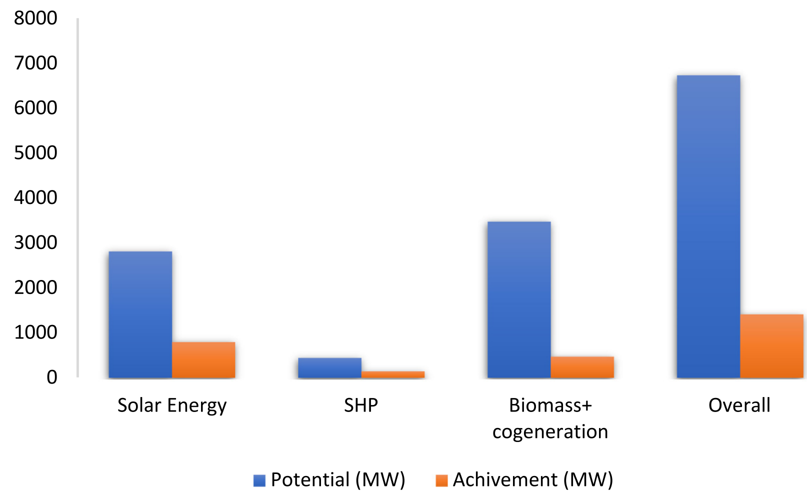

Fig. 6. Potential realization of different RE technologies in Punjab.

2.10% nitrogen, 0.046% phosphorous and 2.20% potassium is used as manure for crop production. So far, about 1,75,000 family size (i.e., from 1 to 6 m^3 capacity) biogas plants have been set up in Punjab. For the state of Punjab, the HRT of a biogas plant is 40 days, there are three popularly known models of family size biogas plants approved by the MNES, Government of India. These are the KVIC model, Janta Model and Deenbandhu Model. Though the basic principle of biogas production is the same in all the three models, they differ in design, shape and their requirement of space and their installation cost. Because of the lack of managerial and technical know-how regarding selection, installation and operational aspects of a biogas plant, the full potential of the biogas producing material is not utilized, and the plants often function below the desired efficiency level. Very often, it occurs that selection of an unsuitable model of biogas plant of capacity not matching the availability of the raw material (i.e., cattle dung), and the actual requirement of biogas for a family renders the biogas technology an uneconomical affair (see Fig. 7).

5. Scope of biogas power generation

Biogas power generation can be economically feasible in state of Punjab due to the favorable conditions of raw material, infrastructure, climate and government subsidies. In this section various factors are discussed in detail which can support the statement of biogas power production in state from decentralized renewable resources.

5.1. Climate

Temperature is one of the crucial parameters that determines efficiency of anaerobic digestion. Anaerobic digestion is basically divided into three types on basis of temperature described as psychrophilic (15 °C), mesophilic (35–50 °C) and thermophilic (50–70 °C).

Biogas production rates tend to increase with rise in temperature because majority of methanogens belong to mesophilic range and grow quickly at higher temperatures resulting in the higher degree of conversion of organic matter to biogas (Ramaraj and Unpaprom, 2016; Pandey and Soupir, 2012; Rashed, 2014). Usually biogas plants are operated at mesophilic temperature range as it is more economical and energy efficient to heat slurry to that extent. In the countries having cold climate throughout the year, most of energy produced by power plant is consumed for slurry heating purposes which decrease the overall efficiency of the power plant. Accordingly, it is always economical and effective to install plant in the region with hotter weather conditions reducing the cost of heating equipment and minimum wastage of energy.

Climate of Punjab region can be considered as an appropriate for biogas production. The location of Punjab state is in subtropical region so there is variation in temperature throughout the year and the weather is usually hot as represented in Fig. 8. The ambient temperature of substrate is at optimum range and minimum amount of external heat is required for operation of biogas plant. It is easy to maintain the higher slurry temperatures because of hot climate throughout the year. The higher slurry temperatures will increase biogas production and decrease hydraulic retention time. This will result into lower active slurry volumes and therefore lower biogas plant volumes. Hence the overall capital cost of plant can be reduced as compared to cold region areas.

Cost effectiveness of Biogas plant depends on maintenance of digester slurry temperature higher than the ambient temperature.

Energy required for heating the slurry can be calculated using the first law of thermodynamics.

$$Q_T = m \cdot c \cdot (T_1 - T_2) \tag{1}$$

From the above equation it can be observed that the greater the difference in T_2 and T_1, the higher the energy required to heat the slurry. Temperature in Punjab is reaches to high of 41 °C in summers. The extra cost of heating will be reduced during the major part of year.

5.2. Biogas market

The use of renewable energy sources experienced a significant growth, providing 19.2% of global fuel energy consumption in 2014 (REN21, 2019). Biogas is one of the viable alternatives to the burning energy question. In India about 20,700 lakh cubic meters of Biogas is produced in year 2014–15 which is equivalent to 5% of total LPG consumption in the country. The government is also extending substantial subsidy for setting up of new biogas plants (Abhishek, 2019).

5.3. Availability of raw material

All organic material is prone to anaerobic digestion such as agricultural waste (crop residue, animal manure etc.), waste from

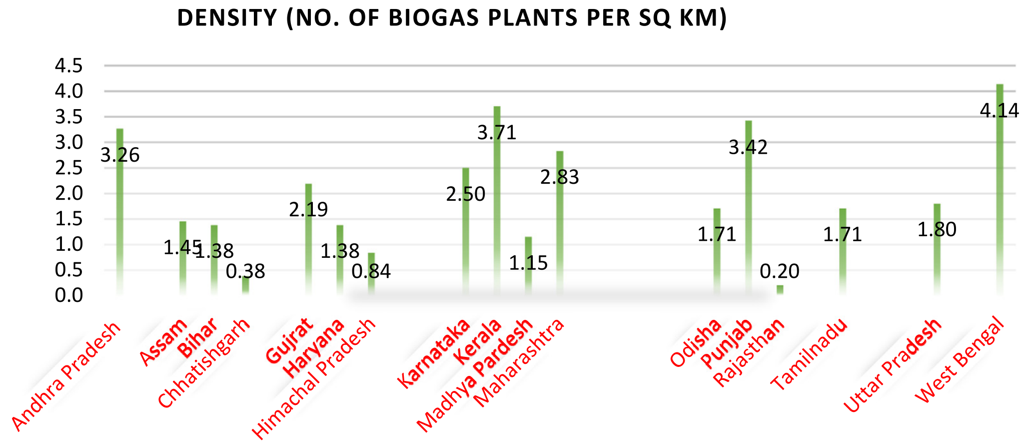

Fig. 7. Number of domestic biogas plants per km^2 in different states of India.

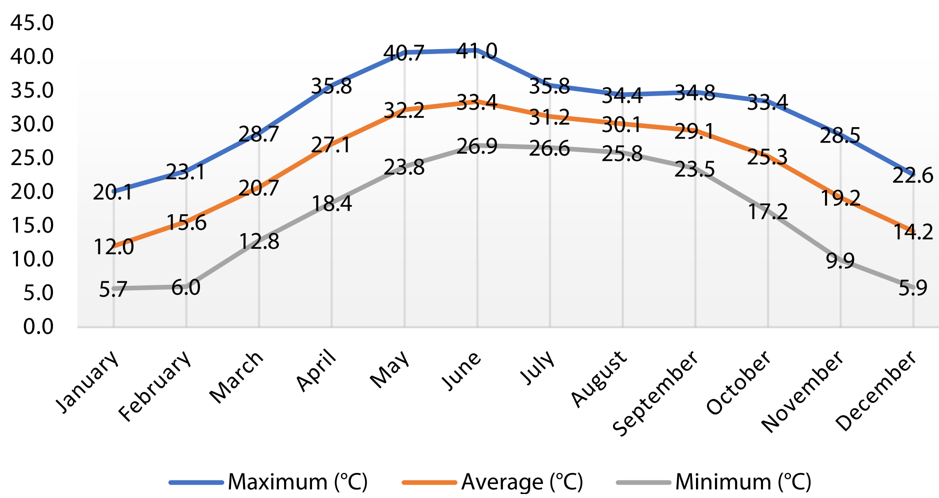

Fig. 8. Temperature range in Punjab throughout the year.

Table 1
Methane yield by various feedstocks and VS content (Zhang and Zhang, 1999; Amon et al., 2007; Elango et al., 2007; Kaparaju et al., 2010).

Biomass	DM (%)	VS (%) of DM	Methane yield (m^3 kg^{-1} VS)	Potential of methane production (MCM/yr)
Dairy manure	40–45	80	0.358	1.89×10^4
Pig manure	5–8	80	0.356	–
Poultry manure	35–39	80	0.410	2.99×10^3
Food waste	10	80	0.500	–
Rice straw	92	79.5	0.470	4.32×10^5
Wheat straw	90	80	0.324	1.22×10^2
Municipal solid waste	45	50	0.360	–

food processing industry (residue of fruit and potatoes processing and animal slaughterhouse), sewage sludge and household waste. The organic matter containing lignin cannot be used for biogas production as the bacteria cannot decompose lignin rich matter either it may be less economical because of pre-treatment of substrate before feeding to digester. Potential of methane production by various feedstocks has been demonstrated in Table 1.

5.3.1. *Animal waste*

As discussed earlier, Punjab is highly agricultural intensive state. Besides this, state is also rich in animal husbandry such as dairy farming, poultry, piggery etc. Punjab is the second largest milk producing state in India. Almost every household in the villages is involved in cattle harvesting starting from 2 cattle to a large dairy farm of 200 above cattle. As per livestock census in 2011 there are 16 794 076 livestock and poultry in the state which produces massive amount of wet and dry manure. There is huge poultry population of 70 million in the state (Agriculture MOF, 2012). Small portion (10%–15%) of this waste produced by cattle is used for direct cooking purpose directly or by domestic biogas plants. Rest 85% of the cow dung is stored in an open pit for using it as manure in fields every 4–5 months after the harvest of each crop. The open storage produces tremendous amount of greenhouse gases and is not an environment friendly. The fresh manure can be borrowed from the farmers at very minimal rates and can be used for biogas production.

Quantity of dung can be calculated by following equation:

$$(QAD)\,i = \sum_{i=1}^{n} (N)\,i \cdot (D)\,i \tag{2}$$

Table 2
Animal waste generated per year.

	No. of animals "in thousands"	Waste generated (MMT/yr)
Cattles	7587	53.1
Poultry birds	16,794	7.3

The surplus availability of animal waste can be collected and used for large scale biogas plants (see Table 2).

Cow dung at domestic level is used in various ways such as:

- For domestic biogas plants.
- Directly for cooking and heating in form of dung cakes.
- As fertilizer in the fields.

As cow dung has number of different usages so, it is very important to calculate the surplus amount of animal waste available for large scale biogas plant in the particular area. For this purpose, a survey has been done among the large number of rural families in Mansa district to know the average amount of surplus animal waste available. Details of survey are disclosed in Table 3. The 4% of the total animal dung per day in Bathinda district in Punjab is used for running the family type biogas plants.

Energy potential from surplus animal dung can be determined by multiplying the net supply potential of surplus animal dung by HHV. Each type of large animal dung has a different HHV.

The modification of Bhattacharya model is done for estimating the energy potential (Singh et al., 2008).

$$Q_i = \sum_{i=1}^{n} (SADi \cdot HHVi) \cdot \eta_c \tag{3}$$

5.3.2. Crop residue

From last few decades Punjab is a home for intensive cultivation of rice and wheat. Rice is grown in over 2.84 million hectares and wheat in 3.51 million hectares in state of Punjab (Adviser, 0000). After harvesting of rice, the straw leftover is burnt in open field due to reason of lack of waste management infrastructure and energy conversion technologies. The production of rice in the state has also increased to 1 658 800 tonnes in 2016–17. With the increase in production of rice there is a concomitant increase in the production of residue (rice straw), which is approximately 20 m t (Sapp, 2018). Every year around 80% of rice straw and 20% of wheat straw (Sidhu et al., 1998) is burnt creating a huge environmental problem in north India. The burning of residue results in substantial loss of plant nutrients contained therein and also adversely affects the nutrient budget in the soil. Experimental studies confirm that burning of 1 ton of rice straw produces 3 kg of particulate matter, 60 kg of CO, 1460 kg of CO_2, 199 kg of ash (Jenkins and Bhatnagar, 1991). The majority of wheat straw is used as fodder for cattle, but rice straw cannot be used because of it is hard to digest an unsuitable for the animals.

Table 4
Availability of different crops residue in state of Punjab.

Crop	Area under cultivation "in thousand hectares" (Adviser, 0000)	Total residue (kt yr^{-1})	Surplus (kt yr^{-1})	Current used (kt yr^{-1})
Rice	2845	10 436	8349	2087
Wheat	3510	18 927	9134	9193
Maize	133	300	257	43
Sugarcane	70	123	–	–

Amount of rice straw produced can be calculated by equation:

$$Q_{RS} = P_{RR} \cdot SGR \tag{4}$$

Presently, there is not much alternative use of paddy straw out of agriculture. The viable use at present is in-situ management in the field, composting or mulching. Ex-situ usage can cogeneration and anaerobic digestion for power production. But according to Trivedi et al. (2017) the energy yield obtained from biomethanation of paddy straw is 30% higher than the bioethanol process. This study directs towards the route of anaerobic digestion for power production using rice straw.

According to Trivedi et Rice straw has a great potential to produce biogas when undergone pretreatment due to the presence of lignin content. This can be a major challenge to use rice straw in anaerobic digestion process. Various studies (He et al., 2008; Zhang, 2002) proved that by various mechanical and chemical pretreatments the biogas production from rice straw can be enhanced (see Table 4).

5.3.3. Food processing industry

Waste from the food processing industry (e.g., juice production) is produced in the large quantities worldwide and contains high levels of lignocellulose. To some extent, the value-added products are extracted from this waste, but the majority of the waste is currently unutilized and discarded. Energy generation from this waste has been investigated in the form of production of biogas, hydrogen and bioethanol.

Punjab which has served as the food bowl of the nation for decades and now transforming to a food processing hub of the country. The rate of food processing industry is also increasing with the high rates. Various food processing industries in Punjab are as follows:

- agriculture and forestry,
- beverages,
- food,
- food, drink, tobacco and catering industry machinery and equipment,
- livestock and fish,
- organic products.

Table 3
Availability of cow dung in the rural areas in district Mansa of Punjab.

No.	Village in district Mansa	No. of families reached	Total number of livestock	Total amount of waste produced (kg d^{-1})	Domestic usage per day (kg d^{-1})	Total amount of Surplus quantity (kg d^{-1})	Average surplus per family (kg d^{-1})
1.	Heron Khurd	25	150	2250	1290	960	38.4
2.	Heron Kalan	30	180	2700	1480	1220	40.6
3.	Khiwa Khurd	15	55	825	434	391	26
4.	Gurradi	45	258	3870	1589	2281	50.7
5.	Hodla kalan	34	134	2010	756	1254	36.8
6.	Dodra	54	243	3645	1876	1769	32.75
7.	Bir Kalan	34	122	1830	865	965	28.3
8.	Bir Khurd	43	212	3180	1453	1727	40.1
	Total					10 567	31.8

Table 5
Data regarding MSW generation in Punjab.

MSW (2000) MT/day	MSW (2009–11) MT/day	Collected waste	Treated waste	Growth (%)
1266	2794	NA	nil	121

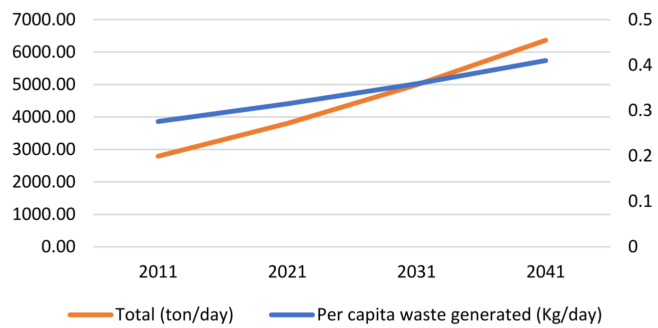

Fig. 9. Municipal waste generation in Punjab.

5.3.4. Sewage waste

MSWM, a critical element towards sustainable metropolitan development, comprises segregation, storage, collection, relocation, carry-age, processing, and disposal of solid waste to minimize its adverse impact on environment. An unmanaged MSW becomes a factor for propagation of innumerable ailments. About 60 million tons of municipal solid waste and about 4.400 million cubic meters of liquid waste are generated every year in the country. Most waste that are generated find their way into land and water bodies without proper treatment causing severe water pollution. They also emit greenhouse gases like methane and carbon-di-oxide and add to air pollution. The problems caused by solid and liquid waste can be significantly mitigated through the adoption of environmentally waste to energy technologies such as bio methanation, combustion, pyrolysis etc. A number of wastes to energy projects have been set up at distilleries, paper-mills, sugar and starch factories etc. Along, with increases in population the amount of water generated by humans is approaching sky high levels. Every year per capita generation of waste is increasing with high rates. According to report of CPCB 2013, in year 1999–2000 state of Punjab generated 1266 MT/day of MSW whereas in 2012 it reached to 3853 MT/day. According to the study by Sharholya et al. (2008) the waste produced by the urban population contains 41% of organic waste. Studies reveal that 90% of MSW is disposed of unscientifically in open dumps and landfills creating hazardous problems to health and environment.

Biodegradable waste has a good potential for generating biogas, which can serve as a fuel, can also be converted to energy as well as to compost which can improve soil health and lead to increase agriculture production. This wet waste can be processed either through bio methanation or composting technology for generating biogas, electricity or compost for use as nutrient and prevent such wastes reaching the landfill.

According to reports P. Commission report (Commission P., 0000) 3853 MT/day waste is collected through out Punjab but only 365 MT/day is treated. The reason for so low percentage of waste treatment is the availability of processing infrastructure and facilities (see Fig. 9 and Table 5).

6. Economic aspects

Economic feasibility of any power project is utmost important besides the reduction in carbon emissions and checking the pollution (E BMA, 2012). Economic evaluation of biogas plant is based on the well-defined input parameters from the literature, experiments, calculations (Sooch et al., 2013; Maurice et al., 2002; OudeLansinka SAGMPMMAMPGJM, 2010; Lantz, 2012; Wresta et al., 2015) and statistical data.[1,2] The availability of raw material is well defined in many researches, but the further step is to determine the optimal size of a biogas plant to reduce the overall expenses and reduce cost of power generation.

Optimum size of biogas plant can be determined by Jenkins model (Jenkins and Bhatnagar, 1991). This model involves input data from the economical information with respect to geographical location, collection and transportation cost. As already discussed, the biomass is spatially distributed resource it is very important to select the optimum location of plant which will lead to minimization of transport cost. Singh et al. (2010) demonstrated that the unit cost for transportation decreases with increase in a distance. A mathematical model for cost evaluation of collection and transport was derived as following (Jenkins and Bhatnagar, 1991):

$$q_c = \int_0^{r_0} \rho \cdot 2\pi \cdot r \cdot dr = \pi \rho r_0^2 \tag{5}$$

$$\begin{aligned} \textit{Total collection cost of biomass} &= \int_0^{r_0} \left(C_r 2\pi rdr + C_t r_p 2\pi rdr\right) \\ &= \pi \rho r_0^2 \left[\frac{C_r}{\rho} + \frac{2}{3} C_t r_0\right] \\ &= q_c \left[\frac{C_r}{\rho} + \frac{2}{3} C_t r_0\right] \end{aligned} \tag{6}$$

Unit collection cost C_c,

$$C_c = C_r \frac{1}{\rho} + \frac{2}{3} C_t r_0 \tag{7}$$

The average density of rice straw distribution is 238 t/km^2 (Jenkins and Bhatnagar, 1991). According to Jenkins the larger plants may cost less per unit power production due to lower cost of unit raw material. Following model was developed to calculate the optimum size of plant.

$$\min Z = aM^{s-1} + bM^{1/2} + c \tag{8}$$

$$M_{opt} = \left[\frac{2a(1-s)}{b}\right]^{\frac{1}{1.5-s}} \tag{9}$$

$$a = M_0^{1-s}(fK_0 h^{-1} + R_0) \tag{10}$$

$$b = C_t h^{\frac{1}{2}} q^{\frac{-1}{2}} E^{\frac{-3}{2}} \tag{11}$$

$$C = C_c E^{-1} \tag{12}$$

$$f = \frac{i(1+i)^n}{(i\,(1+i)^n - 1)} \tag{13}$$

$$E = \frac{H\eta}{3.6} \tag{14}$$

Eq. (9) can be used to determine the optimum capacity of a biogas plant. The input variables must be accurate and precise to obtain the best results. Fig. 10 represents the flow chart of value chain and actors on different stages of capital and material flow.

According to study by Chaudhary and Goyal (2014) the biogas plant established in Haibowal dairy complex, Ludhiana is profitable with capital output ratio of 2.2 and payback period of 4 years.

The electricity power produced by biogas plant can be sold directly to Punjab state power Corporation Limited (PSPCL) and various other private industries in the state. The biogas plant in Punjab can produce electricity at cost of Rs. 3.50 per kilowatt (Chaudhary and Goyal, 2014).

[1] Ministry of New and Renewable energy Govt. of India website: mnre.gov.in.
[2] www.indiastat.com.

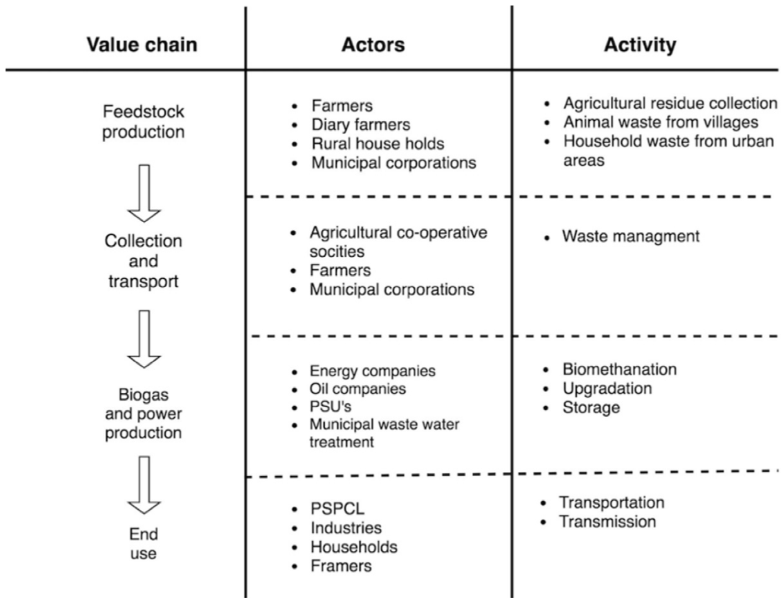

Fig. 10. Representation of value chain, and actors on different stages of capital and material flow.

7. Government policies

7.1. Initiatives & subsidies

According to biofuels policy of India (No B, Complex C.G.O., 0000) setting up of plants and creation of any new infrastructure for production, storage and distribution of biofuels is declared as priority sector for purposes of lending by financial institutions and banks. National Bank of Agriculture and Rural Development (NABARD), Indian Renewable Energy Development Agency (IREDA) and Small Industries Development Bank of India (SIDBI) and many other financial agencies as well as banks are actively involved in providing the finance for various activities under the entire biofuel value chain, at different levels. Investments and joint ventures in the biofuel sector are proposed to be encouraged. Biofuel technologies and projects would be allowed 100% foreign equity through an automatic approval route to attract FDI, provided biofuel is for domestic use only, and not for export.

The government of India provides significant aid for capacity building, training and development of human resource in context of renewable energy. The educational institutes such as Universities, Polytechnics and Industrial training institutes are encouraged to introduce suitable curricula to cater to the demand for trained manpower at all levels in different segments of the biofuel sector. Initiatives are also taken to promote R&D in energy sector and various application of biofuels. Moreover, various government ministries such as Ministry of Environment & Forests, Ministry of Petroleum & Natural Gas, Ministry of Rural Development and Ministry of Science & Technology deal with different aspects of biofuel development and promotion in the country.

7.2. Biogas based power generation & thermal application programme (BPGTP)

During financial year 2017–18, Biogas based power generation (off-grid) programme (BPGP) was implemented which is further modified to Biogas based power generation & Thermal application Programme (BPGTP) in 2019–20 after end of 12th five-year plan period. This scheme is introduced for the power generation capacity of 3 kW to 250 kW or equivalent thermal energy from biogas plants of same size ranging from 30 m^3 to 2500 cubic meter per day. Under this scheme different projects are to be undertaken for promotion, deployment and dissemination of new technology including developing manpower skills BDTC's, necessary infrastructure and establish a proper installation and arrangements for operation.

7.3. Biogas development and training centers (BDTC)

Under this programme financial support is provided to establish BDTC's for organizing and conducting specially designed workshops, seminars and training programmes. The main objective is to develop required specifications and standards and standard as well as standard plant operating procedures. CFA also provides support for establishing trained pool of skilled biogas plant operators. The maximum assistance of Rs 100,000 (rupees one lakh) will be sanctioned per event. Table 6 represents the amount of subsidy provided by the central government for setup of biogas plants according to the initial capacity along with the pattern of Central Financial Assistance (CFA) w.e.f 26-11-2018 to 31-03-2020 for all states including other charges (see Table 7).

8. Collection and storage of waste

Rice is grown in 2.85 million hectares in Punjab. So, the biggest challenge can be the collection and storage of huge amount of biomass. To collect the straw large bale systems are required because the area under rice cultivation is very large and the time window to sow next crop is around 7–8 days after rice harvesting. Basically, to drive the large bale systems heavy machinery (110–125 hp) is required but in Punjab the availability of machinery is with the lower hp. Roughly, 90%–95% of tractors in Punjab are with lower PTO power between 35–65 hp. Moreover, all the farmers cannot afford this heavy equipment. As per the available machinery, the cost of bailing the 100 kg of paddy straw is around 50–60 INR and it is sold for 140 INR per 100 kg to the existing plants (Jassowal, 2018). So, for the effective implementation of collection of paddy straw the area of Punjab can be divided into small clusters and the machinery can be provided by the government (see Fig. 11).

Cow dung can be considered as an easily available bioresource that holds a great potential for sustainable development in the near future. At village level the animal manure needs to be

Table 6
Pattern of Central Financial Assistance (CFA) & rates applied under BPGTP w.e.f 26-11-2018 to 31-03-2020 for all states including other charges.

Power generation capacity (kW)	Biogas plant size	CFA subsidy (INR)		Administration charges to programme implementing authorities (INR)	
		Power generation	Thermal application	Power generation	Thermal application
3–20 kW	30 m^3 to 200 m^3	35,000 kW	17,500/kW eq thermal/cooling	10% of the CFA	5% of the CFA
>20 kW up to 100 kW	>200 m^3	30,000 kW	15,000/kW eq thermal/cooling	200,000/- (fixed)	100,000/- (fixed)
>100 kW up to 250 kW	>1000 m^3	25,000/kW	12,500/kW eq thermal/cooling	300,000/- (fixed)	150,000/- (fixed)

[1 USD = 71.52 INR (06.08.2019)].

Table 7
Central financial assistance to power producers by Govt. of India.

Waste resource	Subsidy ([a]million/MW)	Max. Assist. ([a]million/project)
Municipal solid waste	.28	1.41
Urban waste	.28	.70
Industrial waste	.02-.14	.70

[a]USD.

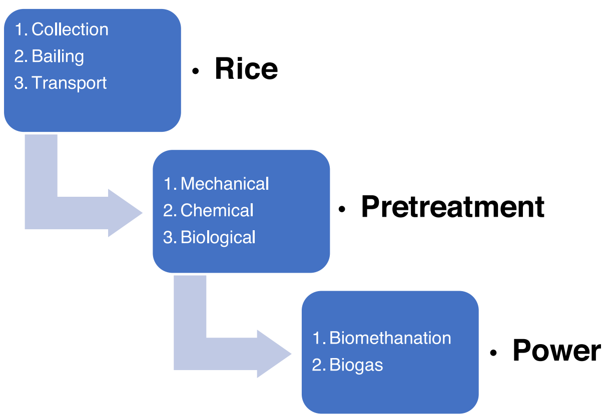

Fig. 11. Flow chart of rice straw processing for anaerobic digestion.

collected on daily basis. The appropriate price for the cow dung should be estimated which could be reliable for both the biogas plant and farmers. Fig. 3 shows the schematic flow of various steps and process flow for centralized biogas plant (see Fig. 12).

Power production from biogas can be a very feasible as per the availability of market and raw material in the state. Analyses show that only farms with a sufficient farm size and enough financial resources are able to invest in biogas plants and thus benefit from the related subsidies. A strong network of suppliers of waste material should be established. 400 ha of arable land are needed to operate a plant with a capacity of 500 kW e depending on the substrate sources and annual operating hours. The plant may face the problems of an inadequate and an erratic supply of raw material. Another problem being faced by the plant is scarcity of labor, which becomes an acute during sowing and harvesting seasons of crops. There are many areas which needs attention to encourage the biogas production in the state. Various shortcomings are listed below which should be rectified.

- Lack of awareness of biogas opportunities
- High upfront costs for potential assessments and feasibility studies
- Lack of access to finance
- Lack of local capacity for project design, construction, operation and maintenance
- Legal framework conditions that complicate alternative energy production and commercialization: for example, the right to sell electricity at local level has to be in place.
- Transportation of waste in the clusters on daily basis.
- Time window too small to sow wheat.

9. Challenges and mitigation strategies in Indian biogas industry

In this section various challenges have been mentioned along with the mitigation solutions. These challenges are common throughout the country so before planning any project these hurdles should be considered and relevant solutions should be proposed. Table 8 demonstrates the various challenges faced by the biogas industry in India along with the possible mitigation strategies. The most subsequent challenge in case of marketing is the sale of fertilizer. It has been observed that the people are unaware about the presence of vital nutrients in the digestate of biogas plant due to which the farmers can deny purchasing the fertilizer produced from the biogas plant. Another aspect of digestate is that the effect of using the digestate as fertilizer is observed after 2 to 3 years after it is exposed to the soil. So, it is very important to aware the farmers about the positive side of using biogas plant digestate as fertilizer.

10. Conclusion

The objective of this paper was to make a contribution to the understanding of the cluster emergence and the development from a co-evolutionary perspective involving technology, industry dynamics and institutions in the Punjab state in India. Various data analysis concludes that there is a huge potential of biogas production in the state. The following are the conclusions:

- The input parameters to determine the optimum capacity of plant cannot be precisely obtained so a deep study on the evaluation of these parameters is required.
- Theoretical biomethane potential is 150 million m^3 per year in the state.
- Proper management of waste can lead to continuous supply of raw material to the biogas plants and the production of power up to 3172 MW.
- Punjab state has a high intensity of power consumption per capita which ensures the long-term reliability of the project. Next step for research can be designing a business model for an effective collection and utilization of decentralized biodegradable matter in the state.
- The estimation of appropriate price for buying and transportation of the animal and agricultural residue is an utmost important.
- Biogas power generation can be the future of green energy in Punjab state in India.

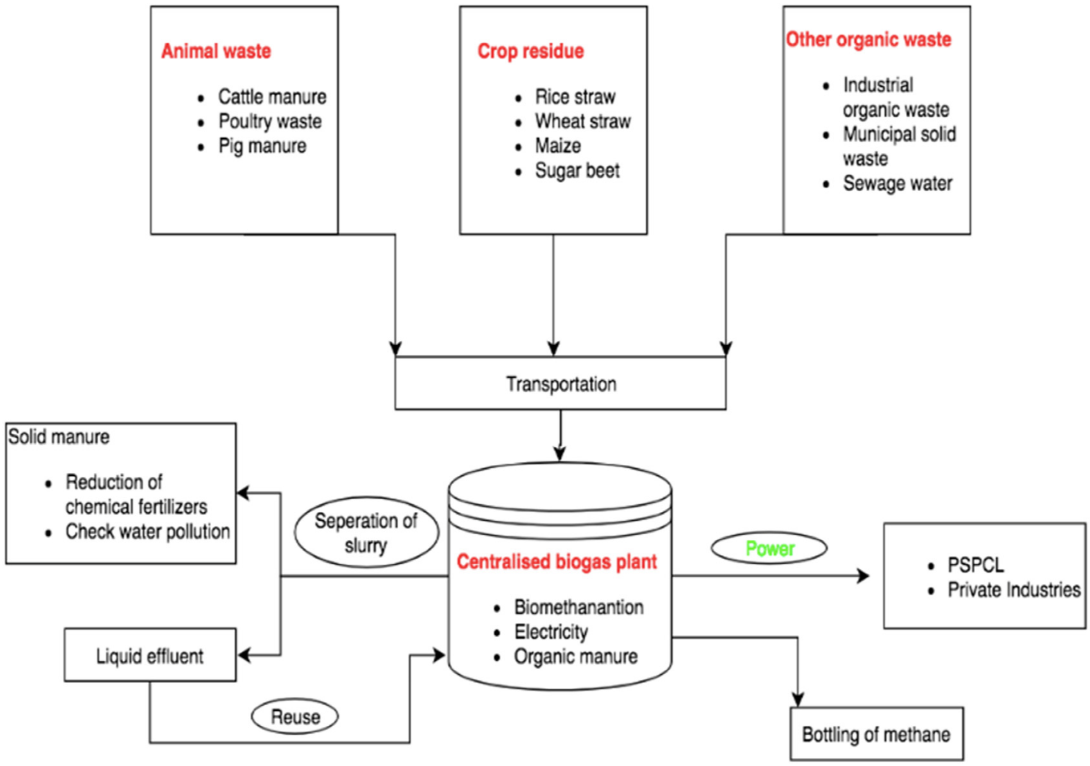

Fig. 12. The main streams of concept of centralized co-digestion biogas plant.

Table 8
Challenges and mitigation strategies in Indian biogas industry.

	Challenges	Mitigation strategies
Market	• Social stigma (NIMBY syndrome) • Market for organic manure is missing • Nascent market with limited players	• Creating awareness, NGO's • Amendment of FCO, Dept. of fertilizers • Collaboration with academic institutions
Operations	• Feedstock security, break in supply chain • Non-segregated waste supply • Availability of skilled manpower	• Resource mapping, emphasis on pre-feasibility • Pan-India adaptation of SWM rules • Capacity building, tailor made course
Finance	• Insecurity over business viability • Lack of credibility of customers • Access to loans from FI • Higher capital cost and payback period	• Securing off-take • Due diligence and certification of players • Innovative financial models • Market development
Regulations	• Inclination towards power-based projects • Lack of concreter standardization • Non-synchronous center and state policies • Long subsidy sanction period	• Balance of centralized and decentralized technology • Expedite development of Indian standards • Building regional groups to work on local and state body policies

CRediT authorship contribution statement

Buta Singh: Conceptualization, Methodology, Writing - original draft, Investigation. **Zoltán Szamosi:** Supervision. **Zoltán Siménfalvi:** Supervision. **Martí Rosas-Casals:** Writing - review & editing, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This research was supported by the European Union and the Hungarian State, co-financed by the European Regional Development Fund in the framework of the GINOP-2.3.4-15-2016-00004 project, aimed to promote the cooperation between the higher education and the industry.

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